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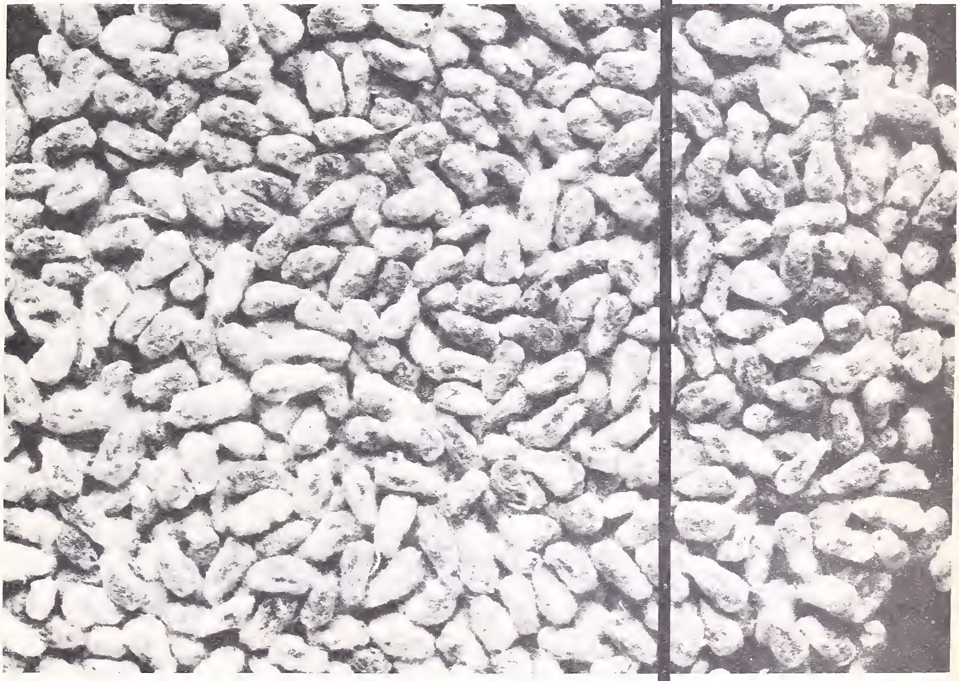
An Electric Meter

for rapid measurement of moisture in cottonseed



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UNITED STATES DEPARTMENT OF AGRICULTURE

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CONTENTS

Page

Summary.......... iii
Introduction.......... 1
    Importance of Moisture Determinations.......... 1
    Relation to Small Lot Grading System.......... 1
Evaluation of Available Methods for Measuring the Moisture Content of Cottonseed.......... 2
The USDA Cottonseed Moisture Meter.......... 3
    Principle upon which Meter is Based.......... 3
    The Electrical Circuit.......... 3
    The Electrode.......... 5
    The Pressure Device.......... 6
    Accuracy of the Meter.......... 8
    Direct Reading Scales.......... 8
Operation of the Meter.......... 8
The Effect of Certain Factors on Meter Accuracy.......... 10
    Pressure.......... 10
    Angle of Center Electrode Point.......... 10
    Electromotive Force in Cottonseed.......... 12
    Temperature.......... 14
    Other Constituents of the Seed.......... 14
    Varietal Differences.......... 14
    Fumigation with Methyl Bromide.......... 15
    Biological Processes in Cottonseed.......... 15
Application of Meter to the Measurement of Moisture in Other Materials.......... 17
Conclusions and Recommendations.......... 18

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This study was planned and conducted under the direction of John W. Wright, Chief, Standards and Testing Branch, Cotton Division. Credit is due Harry F. Cooke and E. S. Bartmess for assistance in the development work.

SUMMARY

Moisture content is the most important factor for the preservation of quality in cottonseed and is of equal concern to the planting seed and processing industries.

Since high moisture promotes rapid deterioration of cottonseed and affects its milling properties, it is considered one of the most if not the most important factor in the determination of grade. A rapid determination of moisture is therefore a necessity for any method of grading individual lots of cottonseed as sold by farmers. Present official methods require 10 to 14 hours for a moisture determination.

A survey of available methods for measuring moisture content pointed to electronics as the most feasible principle on which to base a rapid method. Electrical resistance or conductivity promised to be the best means of making such measurement. A cottonseed moisture meter based on this principle has been developed by the United States Department of Agriculture.

The USDA moisture meter is essentially a very sensitive ohmmeter and an electrode with a means of holding the specimen under a constant pressure. The electrode is a center probe type with cone-shaped center.

The moisture content of cottonseed by the official oven method and the USDA meter were found to be within 0.25 percent of each other in 19 out of 20 trials when duplicate determinations were made. This is considered good repeatability since the oven results include other volatiles as well as moisture.

The USDA cottonseed moisture meter is ready for operation after a 10 minute warm-up period. The sample is placed under pressure for two minutes then the meter is read by depressing switches beginning with the "A" scale until a reading is obtained. A moisture determination can be completed in less than four minutes.

The accuracy of the meter is affected by varying the sample pressure, differences in electrode design, and by temperature. Changes in temperature necessitate a correction factor or the use of a temperature compensating feature in the meter.

Although four varieties of cottonseed out of all varieties now in commercial production in the United States were found to have abnormally high conductivity, the meter could be used with these varieties if a correction factor is applied.

Cottonseed which has been fumigated with methyl bromide may give erratic readings on the meter. The meter is, therefore, not recommended for use with seed treated with this chemical.

It is concluded that: (1) The principle of electrical conductivity measurement of the moisture content of cottonseed is sound and practical. (2) The method is simple in operation, requiring no weighing of the test specimen. (3) The method is satisfactory from the standpoint of accuracy. (4) The method requires less than four minutes for a determination. This is sufficiently rapid to make its use practical for measuring moisture content of small lots of cottonseed at gins. (5) The facility with which moisture content determinations can be made by the electrical conductivity method and the accuracy of the results justify its consideration as an alternate method of moisture assay in connection with the present Official Method of grading cottonseed.

It is recommended that: (1) The USDA cottonseed moisture meter be redesigned for commercial manufacture. (2) Redesigned units be thoroughly field tested. (3) Redesigned units be tested with other oilseeds and cotton lint.

AN ELECTRIC METER
FOR RAPID MEASUREMENT OF MOISTURE IN COTTONSEED

By Marion E. Whitten and Charles E. Holaday, Cotton Technologists

INTRODUCTION

Importance of Moisture Determinations

Moisture content is the most important factor for the preservation of quality in cottonseed. It is equally important to the planting seed and processing industries. Cottonseed with low moisture content will maintain a high germination rate for years.1/ On the other hand, a high moisture content materially reduces the viability of cottonseed so that seed with high moisture content is not used normally for planting purposes. Prime cottonseed with low moisture content has been stored at oil mills for two to three years and still produced prime products.

In the "Standards for Grades of Cottonseed Sold or Offered for Sale for Crushing Purposes within United States," moisture is one of three quality factors. Cottonseed with a moisture content of 12 percent or less may be stored for several months and still yield prime products. Cottonseed with higher moisture content is subject to spoilage and must be milled as soon as possible or cooled to retard deterioration. On the other hand, cottonseed with extremely low moisture content is a problem for the oil mill as the seed must be tempered with moisture for efficient milling.

Relation to Small Lot Grading System

The process of applying the U. S. official standards for grading cottonseed is too elaborate, expensive and time-consuming to be practical in grading small lots of cottonseed. Therefore growers usually sell to ginners at average prices without regard to difference in quality of individual lots. Such a marketing practice involves an element of risk to ginners as well as inequities to growers. In view of this situation, there is need for a system of grading that would be practical for application to sales by farmers.

1/ Simpson, D. M. J. Agr. Research, 64, 407-419 pp. 1942.

Moisture promotes rapid deterioration of cottonseed in storage and affects milling properties of the seed to a considerable extent. For these reasons, it is considered to be one of the most if not the most important factor in the determination of grade. A rapid means of accurate moisture determination is therefore a necessity in grading individual lots of cottonseed as sold by farmers.

EVALUATION OF AVAILABLE METHODS FOR MEASURING MOISTURE CONTENT OF COTTONSEED

At present, moisture or volatile matter in cottonseed is determined by heating a 5 to 10 gram sample of cottonseed at a temperature of 101 degrees Centigrade in a forced-draft oven of approved type for 12 to 16 hours or, preferably, overnight (American Oil Chemists Society, Association of Official Agricultural Chemists and U. S. Department of Agriculture Methods). In another method cracked cottonseed is dried at 103 degrees Centigrade for 5 hours. One relatively rapid method uses a combination balance-infra-red oven for rapid measurement of moisture. The high heat, however, may drive off considerably more volatiles than do other methods.

A survey of possible methods for rapid moisture determination was made by the authors of this report. Electronic measurement was found to be the most promising principle upon which to base a method of moisture determination. Capacitance (dielectric) and conductivity (resistance) measurements both appeared feasible.

The efficiency of ten commercial electric moisture meters on wheat was reported by the Grain Research Laboratory, Board of Grain Commissioners for Canada.2/ The two resistance type meters mentioned in the report were indicated as showing the greatest accuracy; however, these meters were not adaptable in their present form for use with cottonseed. Two dielectric meters which gave standard errors of estimate of ±0.35 and ±0.44 on moisture in wheat were found in the USDA study to have standard errors of estimate of ±0.49 and ±0.56 respectively on cottonseed with comparable moisture content. On higher moisture levels in cottonseed, the standard error was found to be considerably greater.

A survey of other meters was made, but none was found to have the accuracy considered necessary for a rapid grading method for cottonseed.

2/ Canadian Journal of Research, Vol. 27, No. 10, 1949. "A Comparison of Ten Electrical Meters for Determining the Moisture Content of Wheat," I. Hlynka, V. Martins and J. A. Anderson

In view of the lack of suitable equipment for the rapid determination of the moisture content of cottonseed, work was initiated to develop suitable equipment for this purpose. Preliminary studies indicated that the electrical resistance (conductivity) principle offered the best means of obtaining the desired results.

THE USDA COTTONSEED MOISTURE METER

Principle upon which Meter is Based

All factors considered, electrical conductivity appeared to be the most promising principle on which to base an accurate, quick, simple and relatively inexpensive method of moisture determination. This method required, primarily, an ohmmeter suitable for indicating the resistance between two or more selected points in a sample of cottonseed. Obviously, these points must be a fixed distance apart since the electrical resistance (or conductivity) is a function of the distance between the points of measurement.

Preliminary experiments were conducted with a commercial type ohmmeter and an electrode having two parallel probes. The results of these tests indicated that variations in the density of the seed mass caused erratic meter readings. Provisions were then made to maintain the specimen at a uniform density by the application of constant pressure. Subsequent tests with this device revealed that no measurement of the weight of the test specimens was necessary, thus eliminating tedious weighings required with some types of meters.

Additional experiments disclosed that the commercial type ohmmeter was unsatisfactory for use in the cottonseed moisture meter. A meter of greater sensitivity was required; also a provision for voltage regulation in the meter circuit was found essential in order to compensate for changes in line voltage. For use at cotton gins, the meter should be sufficiently rugged to withstand rough handling, without being too expensive to manufacture or maintain.

The Electrical Circuit

The electrical circuit developed for the USDA cottonseed moisture meter is a series type ohmmeter circuit suitable for measuring the resistances of cottonseed with moisture contents of from approximately 6 percent to 23 percent (fig. 1).

In the circuit, V_1 is a cathode couple isolating amplifier. This means is used to provide the extremely high impedance input which is necessary on the very sensitive ranges. V_1 also provides appropriate D. C. voltages to operate V_2. V_1 may be considered as a very sensitive balanced bridge circuit, capable of applying voltages to the grids of V_2. The

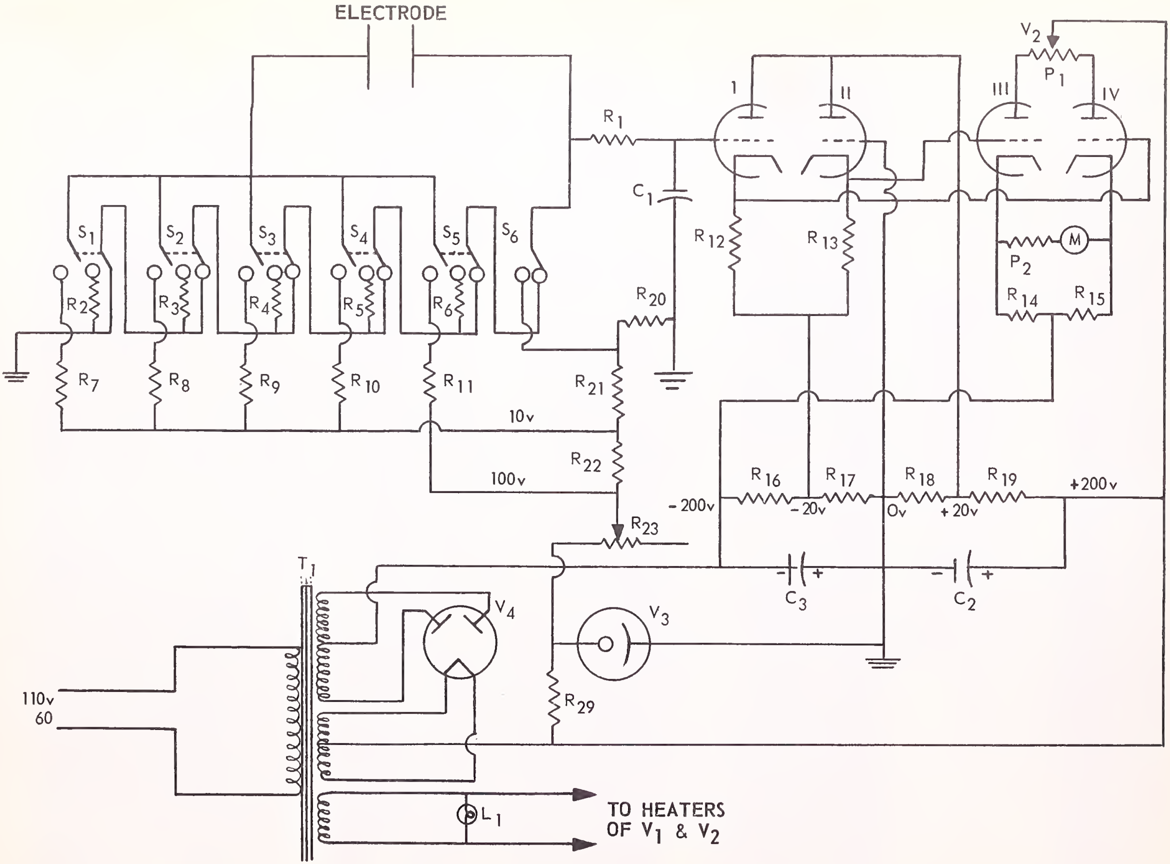

Figure 1.--Circuit diagram of the USDA Cottonseed Moisture Meter

U. S. DEPARTMENT OF AGRICULTURE NEG. 3920-57 (3) AGRICULTURAL MARKETING SERVICE higher the resistance across the electrodes, the smaller the voltage sent to grid I. A rise in potential on grid III of V_2 will cause cathode III to rise. Plate III will drop slightly since it has a load resistor. The increase in voltage tends to reduce conduction through this section of V_2 and cathode IV drops in potential. This differential action is desirable since it increases the voltage across the meter and gives a greater deflection. This deflection can be limited by adjusting the variable resistance P_2 so that 3 volts at input will cause full scale deflection of V_2. Therefore no voltage difference appears across the meter when no voltage is impressed on grid I of V_1. The variable resistor P_1 is used to maintain the meter at zero reading in order to assure proper alignment of the instrument. The meter deflection for this type of circuit is inversely proportional to resistance and directly proportional to moisture.

The power supply is a 50 milliampere transformer with a network designed to give 4 different voltages balanced above and below ground. The hundred volts necessary for use on the extremely high resistance circuit (low moisture range) and the 10 volts used on the other 4 circuits are regulated by a voltage regulator tube V_3.

The Electrode

One of the early problems in the development of the USDA cottonseed moisture meter was the design of a suitable type of electrode for use with cottonseed. A number of modifications of two basic designs were developed and tested.

One design was a flat surface type electrode on which all contact points were located in the same plane. There was no penetration of the sample. The measurement of the resistance of the sample was made horizontally through that portion of the sample next to the electrode and perpendicular to the direction of applied pressure. Various other types tested had contact points in the shape of concentric circles, half-moons and rectangles. Extensive testing of the flat surface electrodes indicated that the required accuracy for a rapid method of moisture determination in cottonseed could not be obtained with this design.

The other basic design tested was the probe electrode. This type electrode penetrates the sample under test. Two variations were found to be much superior to the flat surface electrode. In one of these the electrode consisted of four probes, the lower end of each probe forming a 60 degree point for better sample penetration. As in the case of the surface type electrode, the measurement of the resistance of the sample is in a horizontal direction and perpendicular to the direction of applied pressure. However, because of the penetration of the sample with the probes, a considerably better averaging effect of the resistance of the seed mass was

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obtained. The results of tests with this type electrode indicated excellent correlation between meter and official oven analyses on certain cottonseed varieties while on other varieties the correlation was not as good. These erratic results were presumed to be due primarily to the different packing characteristics of those varieties of cottonseed. Both the size and shape of the cottonseed appeared to influence the uniformity of packing. The density of the seed mass would, therefore, be expected to be more uniform in the direction parallel to that of the applied pressure.

As a result of these findings a center probe electrode was designed. The first model consisted of a circular plate as the upper contact point and a center probe 3/4-inch in diameter extending 7/8-inch below. The exposed portion of the center probe electrode had a flat surface and served as the lower contact point.

Center probes of various shapes were tested. Results indicated an improved correlation between meter readings and oven moistures when a center probe with a cone-shaped surface was used (fig. 2). The results of tests with center cone-shaped probes of different angles disclosed that the smaller the angle of the point of the center probe, the closer the agreement between the oven results and the meter. An electrode with a center probe having a 30 degree point was found to be the most accurate for use with cottonseed (table 1).

Table 1.--Comparison of official oven moisture results with USDA meter results on cottonseed at 82 pounds per square inch pressure using an electrode with a center probe having a 30° point.

Scale	Moisture range	Coefficient of correlation	Standard error of estimate	Slope of regression line
	Percent		Percent Moisture	
A	18.0-23.0	.991	±.202	.064
B	15.0-19.0	.998	±.181	.046
C	12.0-15.5	.993	±.146	.044
D	9.0-12.5	.983	±.161	.040
E	6.0- 9.5	.972	±.184	.035

The Pressure Device

Requirements of a pressure device are that it be simple, relatively inexpensive, rapidly and easily operated by hand, and that it hold the sample at a uniform density. One pressure device tested was a mechanism similar to a common "scissors" jack with a preloaded spring to maintain

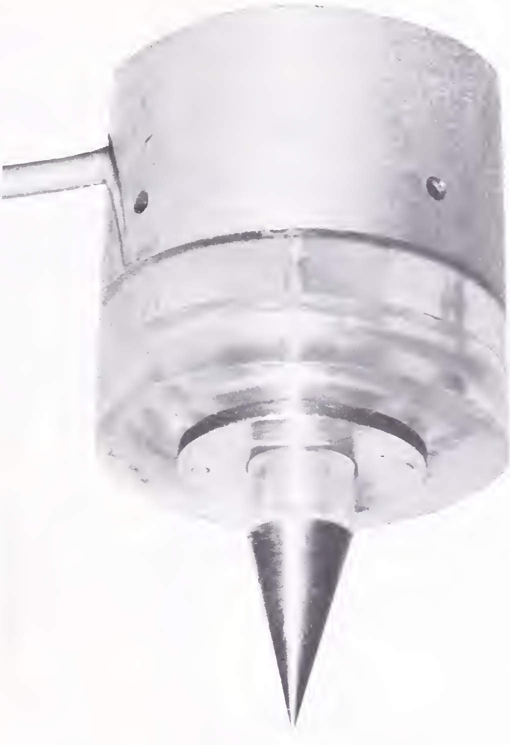

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Figure 2.--Actual size photograph of the probe electrode of the USDA cottonseed moisture meter.

uniform density. Another device employed an air cylinder to obtain pressure. Hydraulic pressure, however, was selected as being the most practical (fig. 3). Although this principle was slower than other methods tested, it was found to be the most economical and the simplest in operation.

It is possible that a pressure device using the "dead" weight principle would also be satisfactory in applying a constant pressure to the sample under test.

Accuracy of the Meter

The accuracy of the USDA Cottonseed Moisture Meter is indicated by the fact that when duplicate determinations were made on a series of cottonseed samples representing a wide range in moisture content, the meter results were within 0.25 percent of the oven results in 19 out of 20 trials. The oven test results include other volatiles in addition to moisture, as well as errors inherent in the method.

An analysis of data obtained from a series of tests using two instruments and two operators indicated that no significant errors could be attributed to different operators or different instruments.

Direct Reading Scales

As previously mentioned, the meter readings of the instrument are in milliamperes. It is necessary, therefore, to use a conversion table to obtain the percentage of moisture in the sample. To eliminate this step, it is contemplated that commercial models of this meter will have scales reading directly in percentage moisture. Provision to illuminate each scale separately during the time it is in use may be made on the USDA moisture meter. This device will preclude the possibility of reading results on the wrong scale.

OPERATION OF THE METER

The USDA cottonseed moisture meter is relatively simple to operate. After the power switch is turned on, a ten minute warm-up period is required before the meter is ready for operation. Adjustments of P_1 and P_2 (as described on page 5) are then made to properly align the instrument.

The specimen cup (approximately one pint capacity) is then filled with cottonseed which is packed firmly and placed on the pressure device directly underneath the electrode. Using the hydraulic mechanism, a pressure of 82 pounds per square inch is then applied to the specimen for a period of two minutes. Beginning with the A scale, individual switches are depressed until a reading is obtained. To determine the moisture content of the

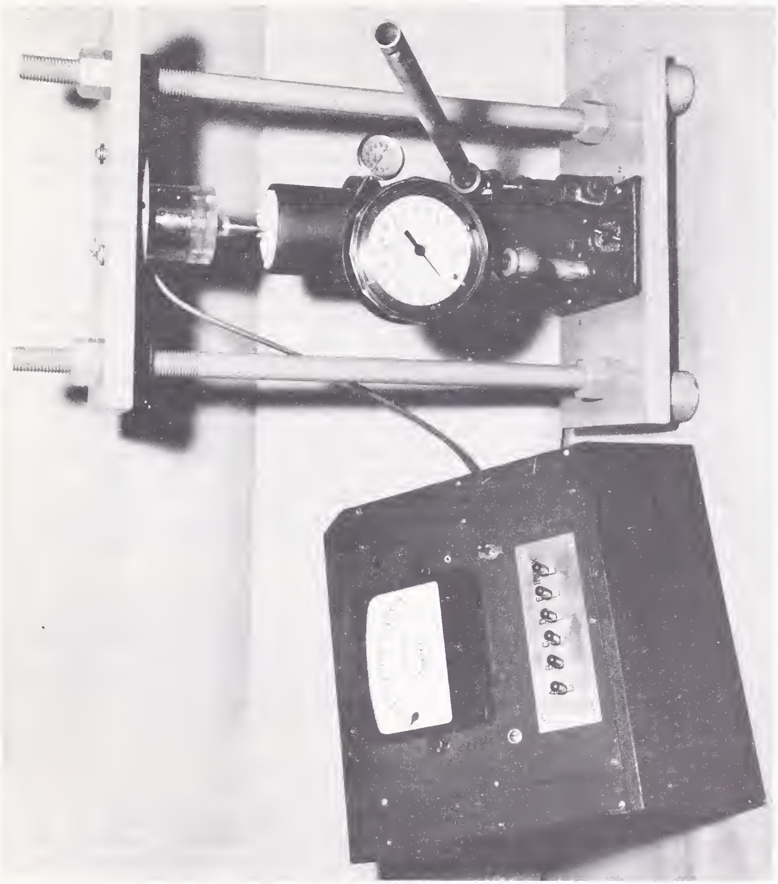

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Figure 3.--The USDA Cottonseed Moisture Meter and Pressure Device

specimen, the meter reading is referred to a conversion table. A correction factor is then applied for sample temperatures below or above 80 degrees Fahrenheit. A complete moisture determination may be made in less than four minutes.

THE EFFECT OF CERTAIN FACTORS ON METER ACCURACY

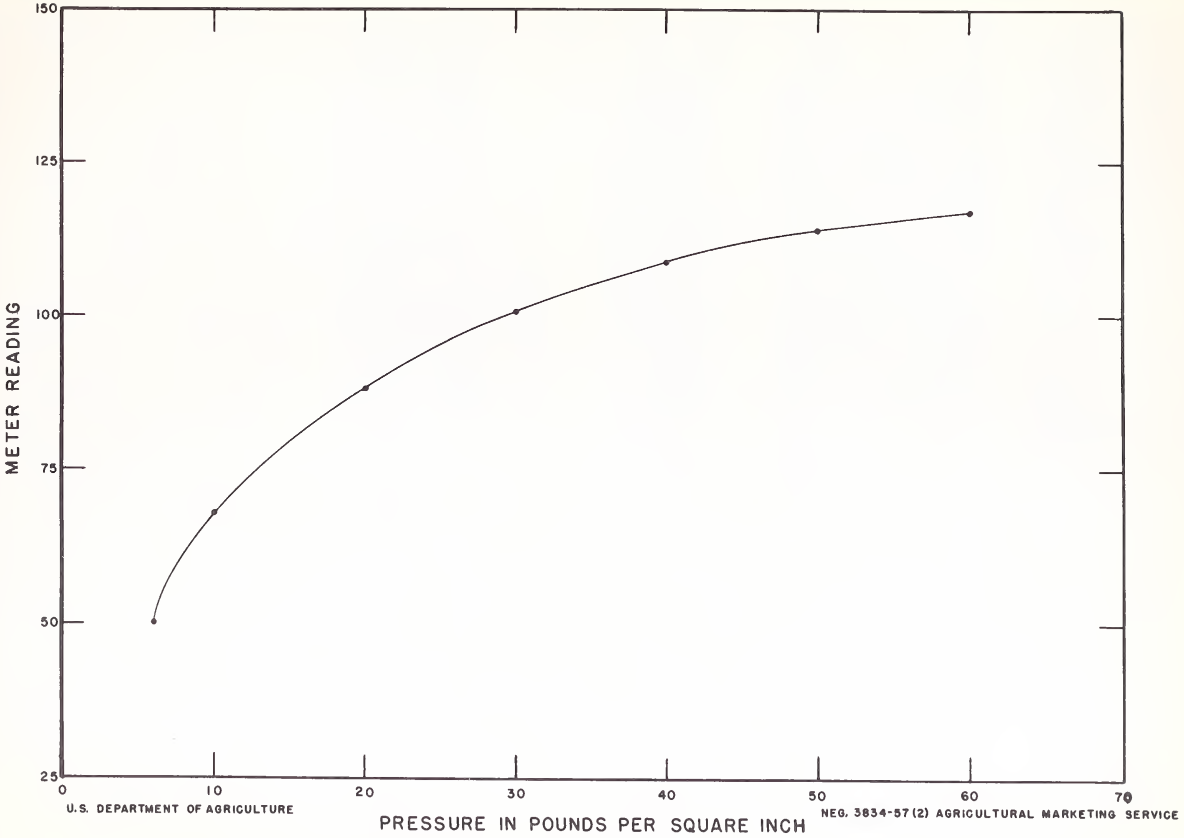
Pressure

As stated previously, it was found necessary to keep the sample under uniform pressure while it is being tested. Using the flat surface electrodes, preliminary tests indicated the critical effect of pressure on resistance measurements of cottonseed. As the pressure on the sample increased, the resulting resistance vs. pressure curve began to flatten out at a certain point (fig. 4). Above this point, differentials in pressure affected the resistance of the seed considerably less than pressure changes below this point. In other tests with the flat surface electrode, pressures as high as 2280 pounds per square inch were used. Surprisingly, good results were obtained with center probe electrode at 0.86 pound per square inch; however, heavily linted samples and those with high moisture content occasionally gave erratic results at this low pressure. The pressure selected for use on the specimen is 82 pounds per square inch, although somewhat lower or higher pressures would probably be about as accurate. The advantage of lower pressure is that the design of the pressure mechanism can be simplified and the cost reduced. Pressure control, however, becomes more critical at low pressure. At high pressures, on the other hand, control of the pressure is less critical, but more expensive equipment would be required.

Another effect attributable to pressure is the positive meter deflection or "creep" (increasing conductivity) which continues for approximately two minutes after the required pressure is applied to the sample. This phenomenon is probably due primarily to the resiliency of the linters since delinted seed cause no appreciable meter "creep" or deflection.

Angle of Center Electrode Point

As stated previously, it was found that the smaller the angle of the point of the center probe electrode, the closer the agreement between oven and meter. An electrode with a 90 degree point was more suitable than a flat surface electrode. Likewise, 60 degree and 30 degree points were found to be progressively more accurate. The difference in accuracy between the 60 degree angle and 30 degree angle is relatively small, but in favor of the 30 degree angle.



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NEG. 3834-57 (2) AGRICULTURAL MARKETING SERVICE

Figure 4.--The effect of sample pressure on meter readings

An explanation for this improvement in accuracy may be that the seed pack more uniformly when the probe encounters a minimum of resistance as it penetrates the samples; for the smaller the angle of the point, the less the friction between the seed and the probe.

According to Hlynka 3/ and others, an inverse logarithmetic relationship exists between the resistance of wheat grains in ohms and percent of moisture content. This same type of relationship was found to exist between the resistance of cottonseed in ohms and percent moisture. Because of the type of bridge circuit used in the cottonseed instrument, the meter readings are in milliamperes, which also have an inverse logarithmetic relationship with the resistance across the electrode. By proper adjustment of the resistance in the series circuit of each scale, it was possible, therefore, to establish between the cottonseed oven test results and the meter readings relationships which for all practical purposes are linear (fig. 5).

The analyses of results with the probe type electrodes indicate that the meter effectively covers a range in moisture content of cottonseed of from 6 to 23 percent. Although the slopes of regression lines for the various scales do not show the uniformity desired, it is contemplated that they will be corrected in connection with the development of a commercial model of the instrument.

Electromotive Force in Cottonseed

It was found, during the investigation, that some samples of cottonseed generated an electromotive force. This electromotive force increased with an increase in moisture content. Tests using unlike metals for each of the electrode quadrants gave potentials as high as 0.4 volt. Using like metal (gold plate), however, voltages were considerably less. The generation of these small voltages by cottonseed was considered to be inconsequential since the meter circuits were operating on voltages considerably greater.

3/ See Footnote 2/, Page 2

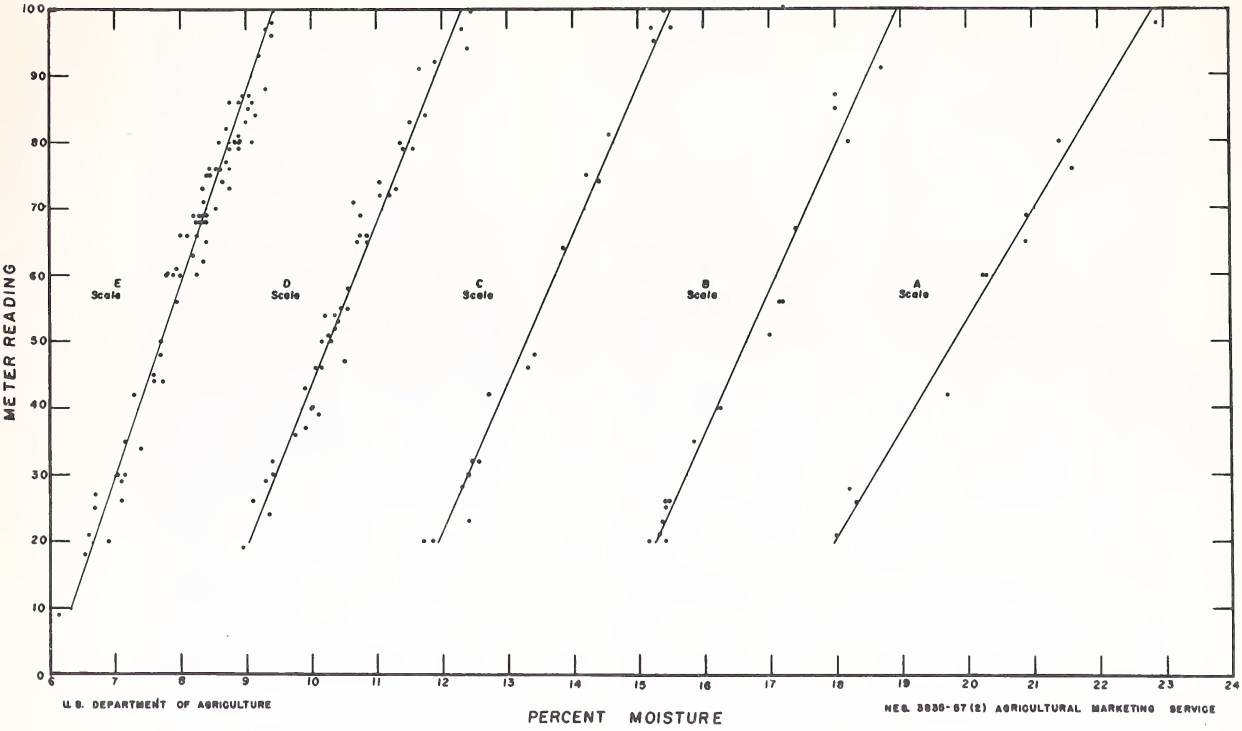

Figure 5.--Scatter diagram showing relationship of moisture content of cottonseed obtained by the official oven method and that obtained by the USDA cottonseed moisture meter using the probe electrode with 30° point.

Temperature

A change in temperature of the sample of one degree Fahrenheit was found to be equivilent to a change in moisture content of 0.045 percent. This effect was the same within the temperature range 70 degrees Fahrenheit to 90 degrees Fahrenheit for all moisture levels from 6 percent to 23 percent. It is necessary, therefore, to make temperature measurements of the sample during the test. One instrument used for doing this was a thermistor mounted on the electrode underneath one of the metallic contact points. Another method tested employed a dial type thermometer inserted into the cottonseed through the wall of the sample cup near the lower edge. The temperature was taken while the sample was under pressure.

It may be found feasible to provide a temperature compensating feature in the circuit of the USDA cottonseed moisture meter, thereby obviating the need for temperature measurements.

Other Constituents of the Seed

In order to ascertain the effect of other constituents of the seed on the accuracy of the meter, a series of 60 samples of cottonseed was tested for moisture by both the official oven method and the meter. These samples consisted of six of the principal commercial varieties of cottonseed. A complete chemical analysis of each of the samples was made, including the determination of oil, protein, free fatty acids, and linters contents. An analysis of the data from these tests (including the oven-meter moisture tests) indicated that varying amounts of the oil, protein, free fatty acids and linters content had no appreciable effect on the meter accuracy.

Varietal Differences

Test results indicated that the Acala 4-42, Mebane, Acala 1517 and Stoneville 2B varieites have abnormally high conductivity as compared with other varieties. Differences in the moisture distribution within the seed were thought to be responsible for this phenomenon, since greater conductivity would normally be expected in those varieties with a greater proportionate amount of moisture in the hull. A comparison of the moisture analyses of the hulls from each variety with like whole seed moisture contents indicated no significant differences, however. Although no further investigation was undertaken to determine the cause for this phenomenon, it is believed that certain conductive substances may be present in greater amounts in the varieties with abnormally high conductivity. An increase of volatiles other than moisture may also contribute to the variations found. The curve formed by the four above mentioned varieties was displaced approximately 0.4 percent (in moisture content) above and parallel to the curve of the other varieties. Although this error is appreciable, an average of the two curves would be within a tolerance of ±0.2 percent for all varieties.

Fumigation with Methyl Bromide

During the course of investigation of the varieties from different regions of the country, it was noticed that very erratic results were obtained when certain samples of seed were tested on the meter. In almost every case it was found that these sample had been treated with methyl bromide, a fumigant for killing the pink boll worm and other insects present in cottonseed in certain areas. In order to determine if the methyl bromide caused these erratic results, new crop cottonseed having no previous treatment was fumed overnight in a conventional methyl bromide fumigation apparatus. After removal from the fumigation chamber, the seed was immediately tested on the meter and also in the oven. Results indicated that a considerable amount of the gas may have been absorbed by the seed since the oven moisture content was approximately one percent higher than that indicated by the meter. Further testing of the seed after two weeks in airtight containers disclosed that its conductivity had increased in some samples which had moisture contents of 10 percent and above, while in the samples with lower moisture content the conductivity remained about the same. The increase in conductivity may possibly have been due to the presence of minute quantities of hydrobromic acid formed as a result of the breakdown of methyl bromide. It was concluded that cottonseed treated with methyl bromide would not give reliable results when tested on the USDA moisture meter.

Biological Processes in Cottonseed

Hygroscopic Equilibrium.--According to Altschul and others, moisture is not distributed equally throughout the seed.[4] Tests under controlled conditions of humidity and temperature indicated that hulls contain more moisture than the entire seed whereas the meats have less than the average. In seed with a very high moisture content (above 20 percent), however, the moisture becomes equally distributed throughout the seed (fig. 6).

Tests indicated that a good correlation existed between meter readings and oven tests even though moisture equilibrium between meats and hulls was not fully established. It was found, however, that if the moisture content of the hulls is considerably higher or lower than that at equilibrium,

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[4] Altschul, A. M. 1948. "Biological Processes of the Cottonseed." Cottonseed and Cottonseed Products, ch. 5, pp. 205-212. Bailey, A. E. Interscience Publishers

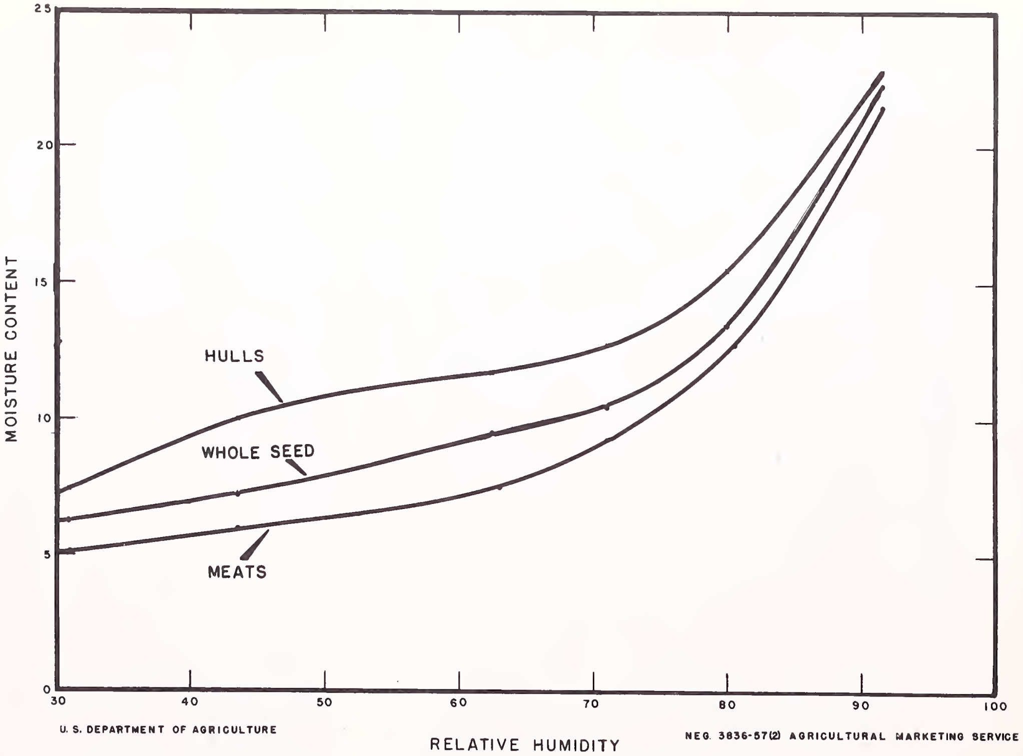

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Figure 6.--Relation of moisture content (wet basis) of the whole cottonseed, meats and hull to relative humidity of the storage atmosphere.[5]

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[5] M. L. Karon, J. Am. Oil Chemists' Soc., 24, 56-58 (1947).

erroneous meter readings may be obtained. If cottonseed having droplets of moisture adhering to the hull surface and/or to the linter fibers is tested, erroneous meter readings may be obtained.

Anaerobic Respiration.--Samples were prepared to a predetermined moisture content for testing on the moisture meter and stored in air-tight containers at 75°F. for a period of six weeks to allow for equilibrium to be established. Under these conditions respiration of the seed was primarily anaerobic. In this type of process, oxidation takes place without the presence of gaseous oxygen. Under such conditions some of the organic substances themselves act as oxidizing agents so that the cellular constituents go through an over-all internal oxidation reduction process.

When this type of breakdown occurs, the seed sugars undergo hydrolysis forming alcohol as the end product. Under certain conditions of temperature and moisture, formation of alcohol may be as high as one percent of total seed weight. This may explain why the meter and oven do not agree on badly deteriorated seed since the highly volatile alcohol would appear as moisture content in the oven test.

Some high-moisture seed which as heavily covered with mold gave a negative "creep" (decreasing conductivity) when tested on the meter. This would appear to indicate that the mold lowers the resiliency of the cottonseed.

Aerobic Respiration.--With aerobic respiration, the organic foodstuffs in cottonseed are oxidized by gaseous oxygen present in the atmosphere. Although no data were obtained concerning the effect of this type of oxidative deterioration on the electrical conductivity measurement of cottonseed, it may be assumed that the effect is similar in most respects to that under anaerobic conditions.

APPLICATION OF METER TO THE MEASUREMENT OF MOISTURE IN OTHER MATERIALS

Results of preliminary tests with the USDA cottonseed moisture meter on a number of varieties of soya beans indicated an excellent correlation between the meter and the official moisture oven. Although sufficient observations were not made for a thorough study of the performance of the meter on soya beans, indications were that the accuracy should be equally as good as was found with cottonseed.

Preliminary tests have also indicated that the meter might be used in measuring the moisture content of raw lint cotton. Results of a few tests indicated excellent correlation between meter readings and official oven results.

CONCLUSIONS AND RECOMMENDATIONS

Based on the foregoing results, it is concluded that:

(1) The principle of electrical conductivity measurement of the moisture content of cottonseed is sound and practical.

(2) The method is simple in operation, requiring no weighing of the test specimen.

(3) The method is satisfactory from the standpoint of accuracy.

(4) The method requires less than four minutes for a determination. This is sufficiently rapid to make its use practical for measuring moisture content of small lots of cottonseed at gins.

(5) The facility with which moisture content determinations can be made by the electrical conductivity method and the accuracy of the results justify its consideration as an alternate method of moisture assay in connection with the official method of grading cottonseed.

It is recommended that:

(1) The USDA cottonseed moisture meter be redesigned for commercial manufacture.

(2) Redesigned units be thoroughly field tested.

(3) Redesigned units be tested with other oilseeds and cotton lint.

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